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EFFECT OF FUEL VOLATILITY ON PERFORMANCE OF A WRIGHT R-2600-8 ENGINE AS INFLUENCED BY MIXTURE DISTRIBUTION

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ADVANCE RESTRICTED REPORT

EFFECT OF FUEL VOLATILITY ON PERFORMANCE OF A WRIGHT R-2600-8 ENGINE AS INFLUENCED BY MIXTURE DISTRIBUTION

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SUMMARY

Object. - To determine the effect of fuel volatility on engine power and economy as influenced by mixture distribution.

Scope. - Tests of four fuels of different volatility were conducted on a Wright R-2600-8 engine at desired cruising power (60 percent of normal rated), maximum cruising power (75 percent of normal rated), normal rated power, and take-off power. The inlet-air temperature at the carburetor intake varied from 46° F to 72° F.

Summary of results. - Although some variation of mixture distribution could be attributed to the different volatilities of the fuels tested, the effect of volatility on power and brake specific fuel consumption was small for the range of conditions tested. At conditions of normal-rated and take-off power, engine operation was noticeably rougher with the fuels that had 90-percent points of 295° F (V-10) and 306° F (V-7) than with the fuels that had 90-percent points of 255° F (V-9) and 270° F (AN-F-28).

INTRODUCTION

The tests described herein were made to obtain information on a maximum permissible A.S.T.M. distillation 90-percent point as limited by satisfactory engine operation. The volatility characteristics of aircraft fuels necessarily represent a compromise inasmuch as good mixture distribution usually demands high volatility, whereas many of the high antiknock components, such as cumene, have low volatility.

In these tests the performance, the mixture distribution, and the temperature distribution of the Wright R-2600-8 engine were investigated for three fuels of different volatility, supplied by the Army Air Forces, and for AN-F-28 fuel, taken from the general laboratory supply.

The tests were conducted at the Aircraft Engine Research Laboratory of the National Advisory Committee for Aeronautics at Cleveland, Ohio, between April 10 and April 19, 1943.

APPARATUS AND PROCEDURE

A Wright Cyclone R-2600-8 engine equipped with a Holley model 1685HA carburetor, a Wright torquemeter, and a Hamilton standard variable-pitch propeller was used for these tests. The engine was installed in a test cell and was cooled by a separate blower that drew air over the engine.

A brief summary of the fuel characteristics is as follows:

Fuel	90-percent distillation point (°F)	Specific gravity	Hydrogen-carbon ratio
V-7	306	0.7374	0.165
V-10	295	.7381	.168
AN-F-28 fuel	270	.7219	.166
V-9	255	.7093	.179

Distillation curves for the fuels are shown in figure 1.

Tests were run at (1) desired cruising power (60 percent of normal rated power), (2) maximum cruising power (75 percent of normal rated power), (3) normal rated power, and (4) take-off power. Table 1 is a summary of the various runs.

The inlet-air temperature was measured by a thermocouple at the carburetor intake. Fuel flow was indicated by a rotameter. The entire fuel-supply system was drained between runs to prevent dilution when fuels were changed. Cooling-air temperatures were air temperatures recorded in the test cell ahead of the propeller.

Mixture distribution was determined by exhaust-gas analysis. Two methods of analysis were employed in order that one could be used as a check against the other. In one method (normal), samples were drawn into bottles and analyzed with a Burrell apparatus. This method involves a combustion pipette in which the products of incomplete combustion are burned in added air. The second method (oxidation) consisted in oxidizing a continuously flowing sample overheated copper oxide and then analyzing the oxidized sample for carbon dioxide in an Orsat apparatus during the run. In one set of runs, oxidized samples were drawn into burettes and were analyzed with a Burrell apparatus.

All exhaust-gas sampling was carried out at a pressure of 6 inches of water, above atmospheric, measured at the point of delivery to the sample bottles or to the Orsat apparatus. An exception to this procedure was the runs at normal rated power (2400 rpm) in which an exhaust-sampling pressure of approximately 15 inches of water was maintained. This pressure corresponded roughly to 85 percent of the maximum (no-flow) pressure available in the sampling system at these conditions.

Exhaust-flame colors provided a rough qualitative check of mixture distribution. A rather effective practical check could be made of individual cylinder performance by this visual means. When the engine was operating at rich mixtures (at a fuel-air ratio of 0.10 or higher), richer-than-average cylinders were observed to emit flames showing a characteristic red cone at the base of the usual dancing blue-white plume. Extremely rich cylinders exhibited a spectacular flashing white flame beyond the red base flame.

Combustion-air flow was not measured during these tests. Previous engine data, which included both air-flow measurements as a function of manifold pressure and fuel-flow measurements at the two carburetor-mixture settings, gave a rough quantitative check of average fuel-air ratio for the conditions of these tests. These data are labeled on the curve sheets "approximate carburetor fuel-air ratio."

Engine temperatures were determined by rear spark-plug-gasket thermocouples and by thermocouples spot-welded to the rear middle barrel surfaces between the fins. A self-balancing potentiometer was used for indication of temperatures. Sufficient time was allowed between the setting of the engine conditions and the recording of the data for all engine temperatures to stabilize. The time requirement for each run was determined by the time necessary for exhaust-gas samples to be taken, which was approximately 5 minutes. Engine temperatures were not observed to require different amounts of time to stabilize for the various fuels.

Power was determined by a Wright torquemeter, which, in principle, measures the reaction on the stationary member of the nose planetary reduction-gear train.

RESULTS AND DISCUSSION

Engine-performance characteristics for the various fuels at all power conditions are given in table 1.

Tests at 60 percent of normal rated power. - The mixture distribution at 60 percent of normal rated power is shown in figure 2. In table 2 results of two methods of exhaust-gas analysis are compared. Fuel volatility had no appreciable effect on mixture distribution, power, or brake specific fuel consumption. The temperature distribution is plotted in figure 3. Although the run for the V-7 fuel was made with a higher cooling-air pressure drop than for the V-10 and the V-9 fuels, the general temperature pattern remained the same. On these and on subsequent plots, dashed-line segments indicate the absence of data for a particular cylinder.

Tests at 75 percent of normal rated power. - Figure 4 indicates some difference in the mixture distribution with the different fuels at 75 percent of normal rated power. The greatest variation in fuel-air ratio from cylinder to cylinder occurred with the V-7 fuel; the V-10 fuel showed a lesser degree of variation. The mixture distribution was good with the V-9 and the AN-F-28 fuels. The temperature distribution (fig. 5) was approximately the same for the various fuels.

Tests at normal rated power. - The mixture distribution at normal rated power was determined by two independent methods of exhaust-gas analysis and is presented in figure 6. Orsat (oxidized exhaust gas) analyses were made during the actual test runs for all four fuels (fig. 6(a)). Simultaneously, oxidized exhaust samples were drawn into bottles for subsequent laboratory analysis with the Burrell apparatus. These samples were taken for the V-7, the V-10, and the V-9 fuels and the results are shown in figure 6(b). These analyses were made in order to compare the two methods of gas analysis. Inspection of figures 6(a) and 6(b) shows that a good check was obtained. The V-7 fuel shows the widest variation of fuel-air ratio, the V-10 fuel slightly less, the AN-F-28 fuel still less, and the V-9 fuel the least variation. The temperature variation, plotted in figure 7, was somewhat affected by the differences in mixture distribution. Engine operation was rough with the V-7 and the V-10 fuels.

Tests at take-off power. - The exhaust sampling at take-off power was not satisfactory (apparently because of nongaseous products of combustion visible as smoke in the exhaust), and the data are not presented. The temperature distribution in figure 8 was substantially the same for the various fuels.

Additional observations. - Greater difficulty was experienced in starting the engine with the V-7 and the V-10 fuels (high 90-percent points) than with the AN-F-28 and the V-9 fuels (low 90-percent points).

Cylinder temperatures could be correlated to some extent with cylinder mixture strength (figs. 9 and 10). In figures 9(a) and 9(b), under the engine conditions listed and with the two fuels conducive to the poorest mixture distribution (see fig. 6), the leanest cylinders tend to have the highest rear spark-plug-gasket temperatures and the richest cylinders have the lowest temperatures. Figure 9(c), however, represents a more nearly normal mixture-distribution condition where, as compared with figures 9(a) and 9(b), very little correlation between rear spark-plug-gasket temperature and fuel-air ratio is to be found. Here, the variation in temperature is mainly attributable to inherent differences in cooling between cylinders. This inherent spread (fig. 9(c)) accounts for approximately two-thirds of the total spread with the widest variation of mixture distribution (figs. 9(a) and 9(b)). Figure 10, which presents data for runs at 2100 rpm, shows but slight correlation between rear spark-plug-gasket temperatures and fuel-air ratio.

The dashed lines shown in figures 9(a) and 9(b) indicate the approximate locus of rear spark-plug-gasket temperatures against fuel-air ratio, where poor mixture distribution applies. These lines are not intended to represent the ideal line of correlation between head temperature and mixture strength, where fuel-air ratio is the sole variable, as shown in figure 11.

The curves in figure 11 were plotted from unpublished data obtained in cooling-correlation tests. Those plots show, for three conditions of power and mixture strength, the change of rear spark-plug-gasket temperature that might be expected to occur with variation in mixture strength to an individual cylinder when mixture distribution is poor. The solid line shown in this figure, for a fuel-air ratio of 0.11, may be considered roughly representative of the trend that produced the effects shown in figures 9(a) and 9(b), as contrasted with figure 9(c).

SUMMARY OF RESULTS

The following statements apply for a range of inlet-air temperatures from 46° to 72° F:

1. The best power and fuel economy were, in general, obtained with the fuel that had the lowest 90-percent point. Differences in performance between the other fuels were relatively slight and not readily attributable to differences in volatility.

2. Some changes in mixture distribution could be attributed to changes in the 90-percent point of the fuel. The widest variations of fuel-air ratio occurred at high powers and rich mixtures. The best distribution characteristics were shown by the fuels having the lowest 90-percent distillation points.

3. Individual cylinders showed changes of temperature due to varying mixture distribution with different fuels, but these changes were considerably less than the differences between cylinders because of other factors. For conditions conducive to the poorest mixture distribution among the cylinders, some correlation between mixture strength and cylinder-head temperatures can be made.

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TABLE 1. - SUMMARY OF PERFORMANCE TESTS OF FOUR ARMY FUELS OF DIFFERENT VOLATILITY ON A WRIGHT R-2600-8 ENGINE

Power condition	Engine speed (rpm)	Manifold pressure (in. Hg abs.)	Carburetor setting	Run	Fuel	90-percent point of fuel (°F)	Brake horsepower	Brake specific fuel consumption (lb/hp-hr)	Cooling-air pressure drop (in. water)	Combustion-air temperature (°F)
60 percent normal rated	2000	27.0	Cruising lean	104	V-7	306	790	0.44	4.6	49
				110	V-10	295	790	.44	2.4	48
				107	V-9	255	795	.44	2.5	46
75 percent normal rated	2100	31.0	Cruising lean	114	V-7	306	1073	0.46	7.5	60
				113	V-10	295	1080	.46	7.5	57
				116	AN-F-28	270	1060	.46	7.7	63
				115	V-9	255	1083	.45	7.5	62
Normal rated	2400	37.5	Full rich	105	V-7	306	1360	0.78	4.5	53
				[a]120	V-7	306	------	-----------	5.7	72
				111	V-10	295	1390	.77	4.1	50
				[a]121	V-10	295	------	-----------	4.7	72
				117	AN-F-28	270	1368	.78	4.7	65
				119	V-9	255	1375	.77	4.9	72
				108	V-9	255	1400	.76	3.5	51
Take-off	2600	43.0	Full rich	106	V-7	306	1570	0.87	8.0	54
				112	V-10	295	1595	.92	4.9	51
				109	V-9	255	1630	.89	5.6	53

[a]Power measurement in error.

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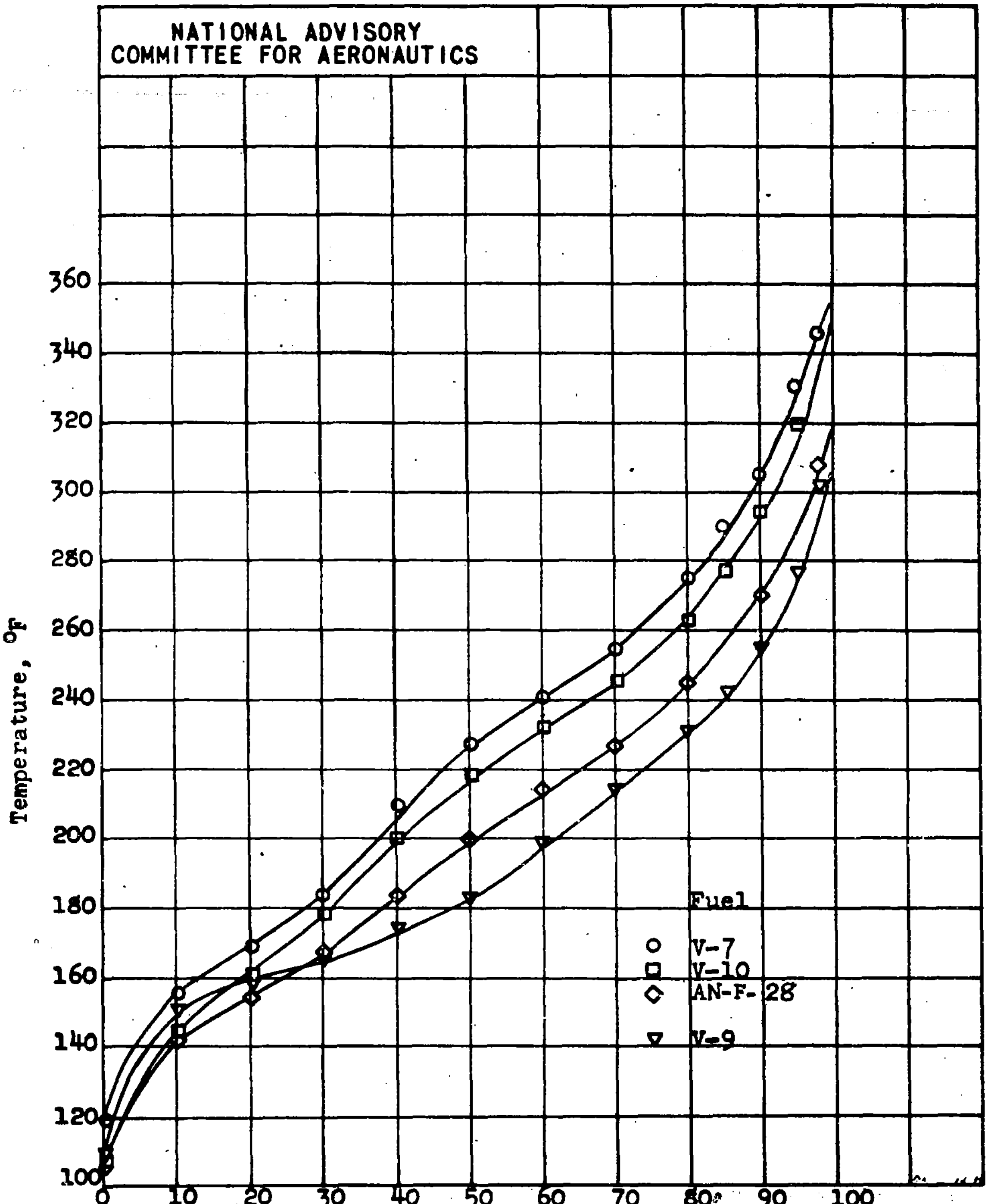

Figure 1. - Distillation curves of fuels used in mixture-distribution tests.

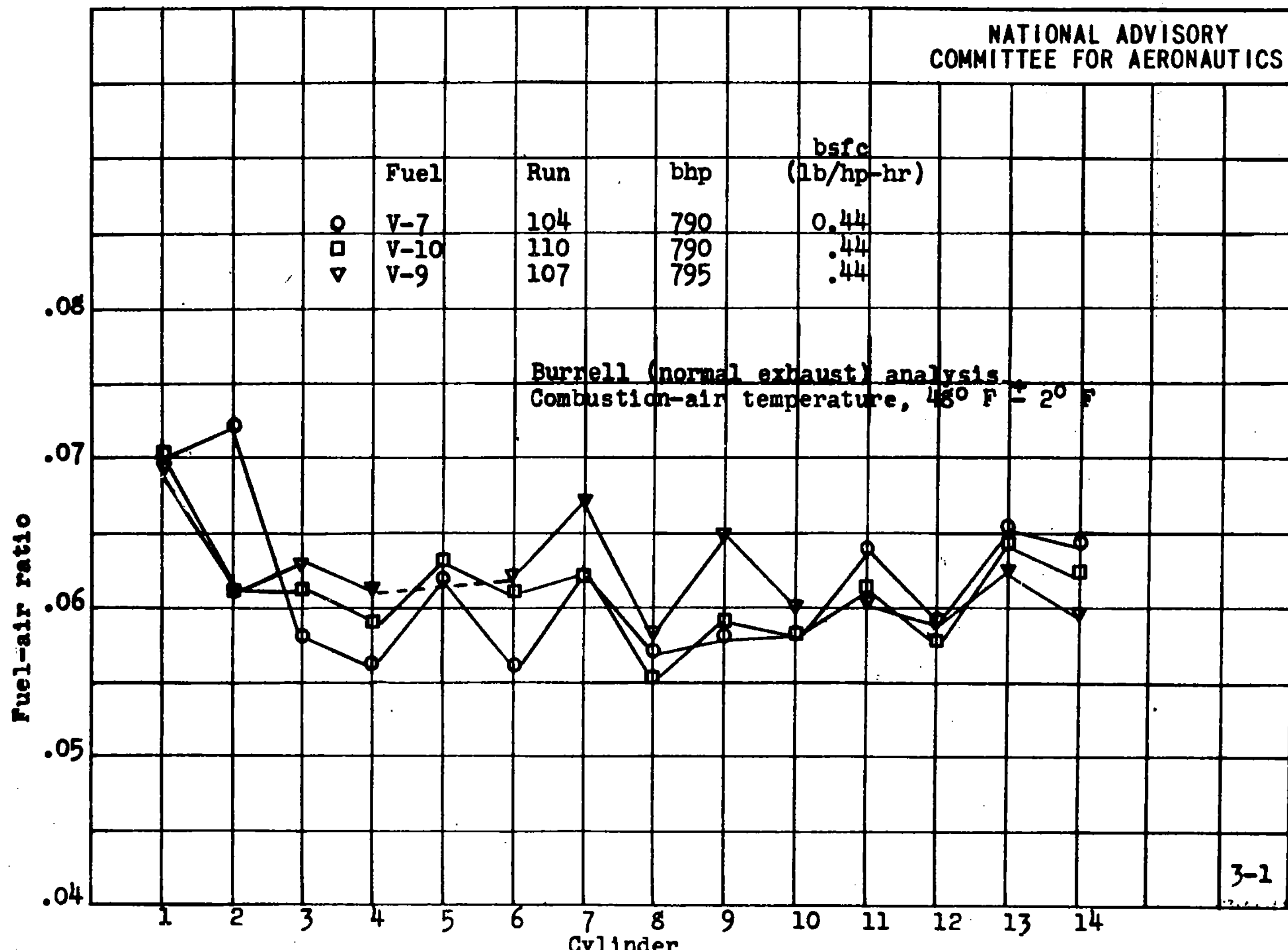

Figure 2. - Mixture distribution of a Wright R-2600-8 engine at 60 percent of normal rated power. Engine speed, 2000 rpm; manifold pressure, 27.0 inches of mercury absolute; carburetor setting, cruising lean; approximate carburetor fuel-air ratio, 0.07.

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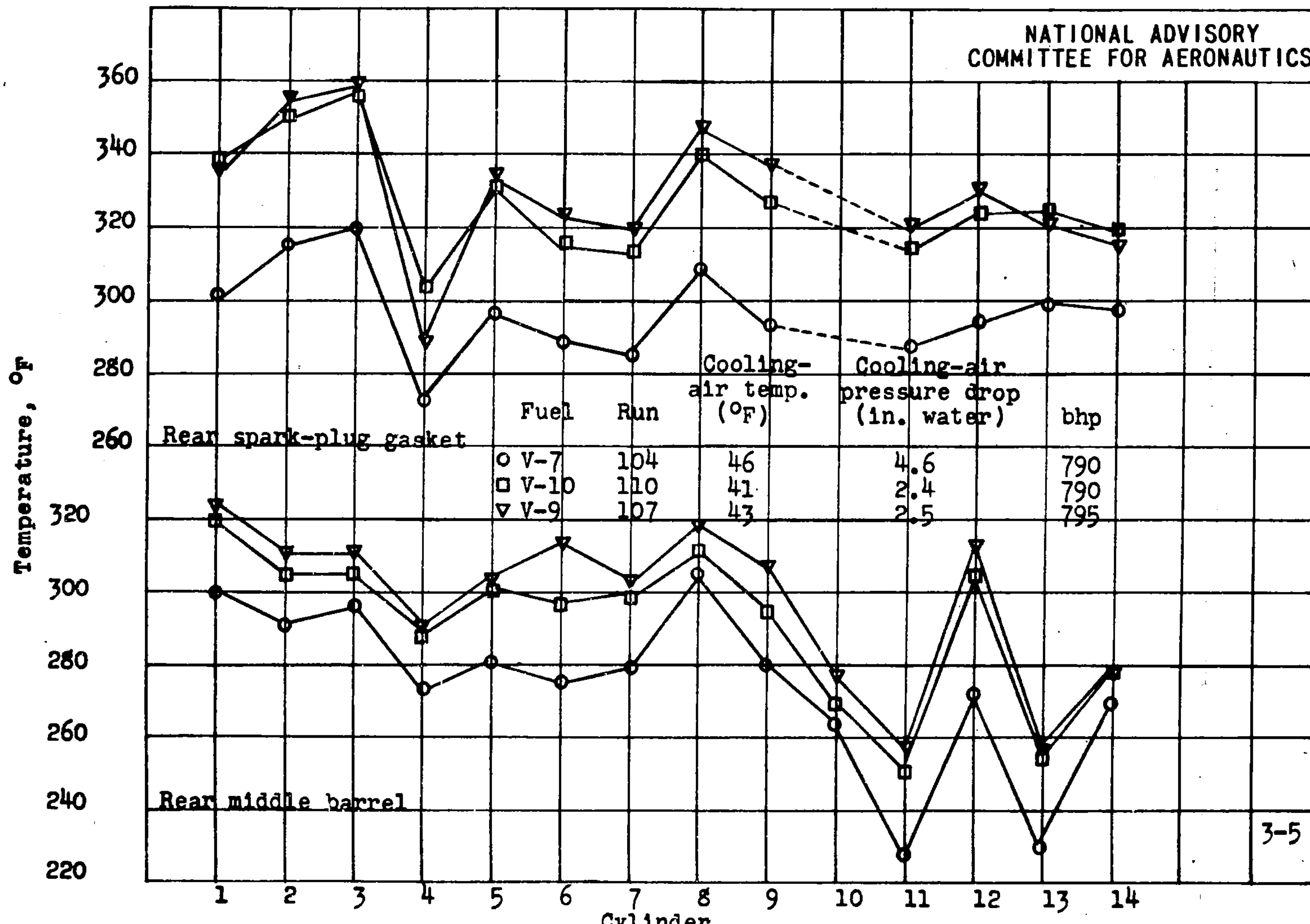


Figure 3. - Temperature distribution of a Wright R-2600-8 engine at 60 percent of normal rated power. Engine speed, 2000 rpm; manifold pressure, 27.0 inches of mercury absolute; carburetor setting, cruising lean; approximate carburetor fuel-air ratio, 0.07.

Fig. 3

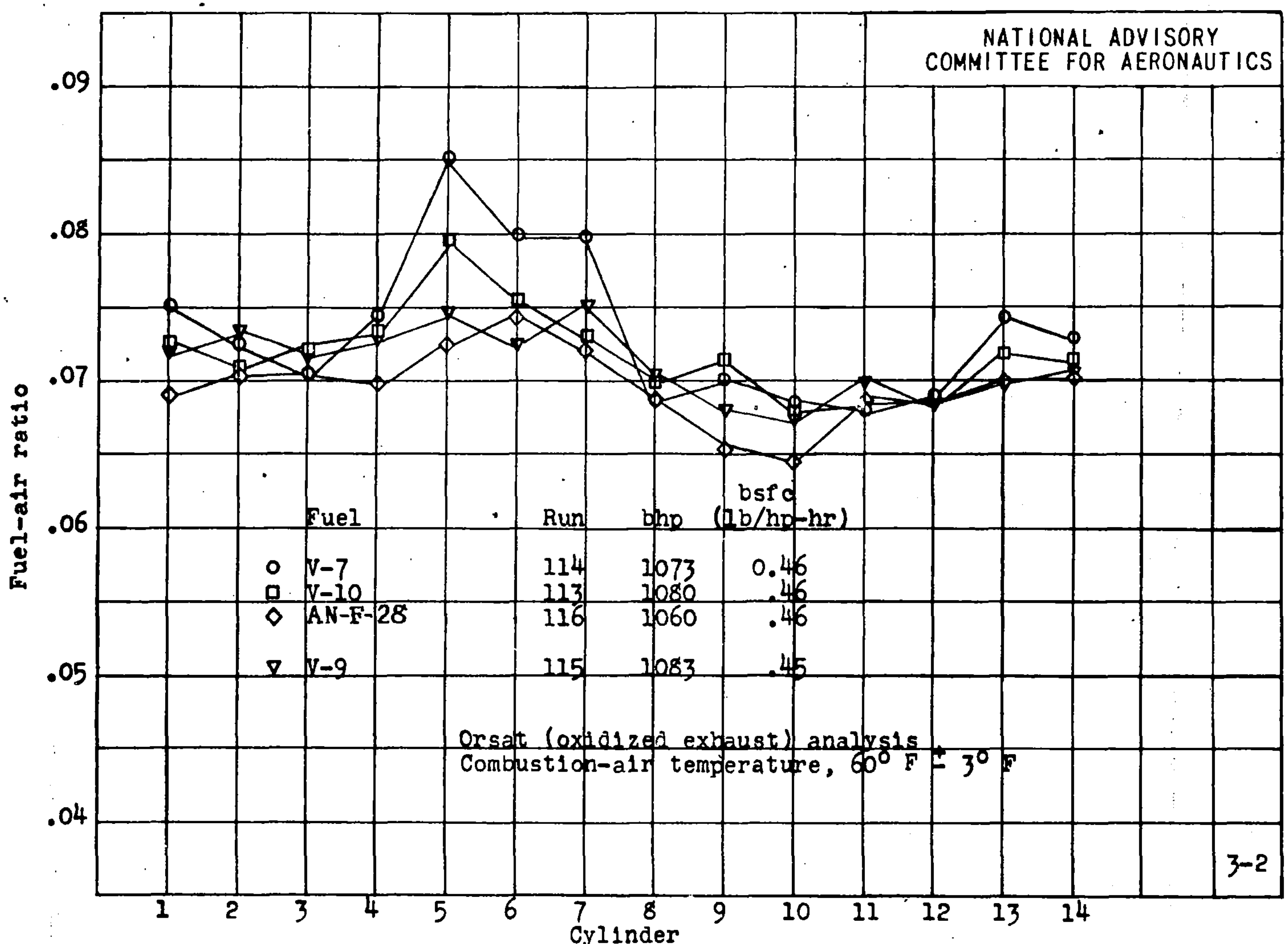


Figure 4. - Mixture distribution of a Wright R-2600-8 engine at 75 percent of normal rated power. Engine speed, 2100 rpm; manifold pressure, 31 inches of mercury absolute; carburetor setting, cruising lean; approximate carburetor fuel-air ratio, 0.08.

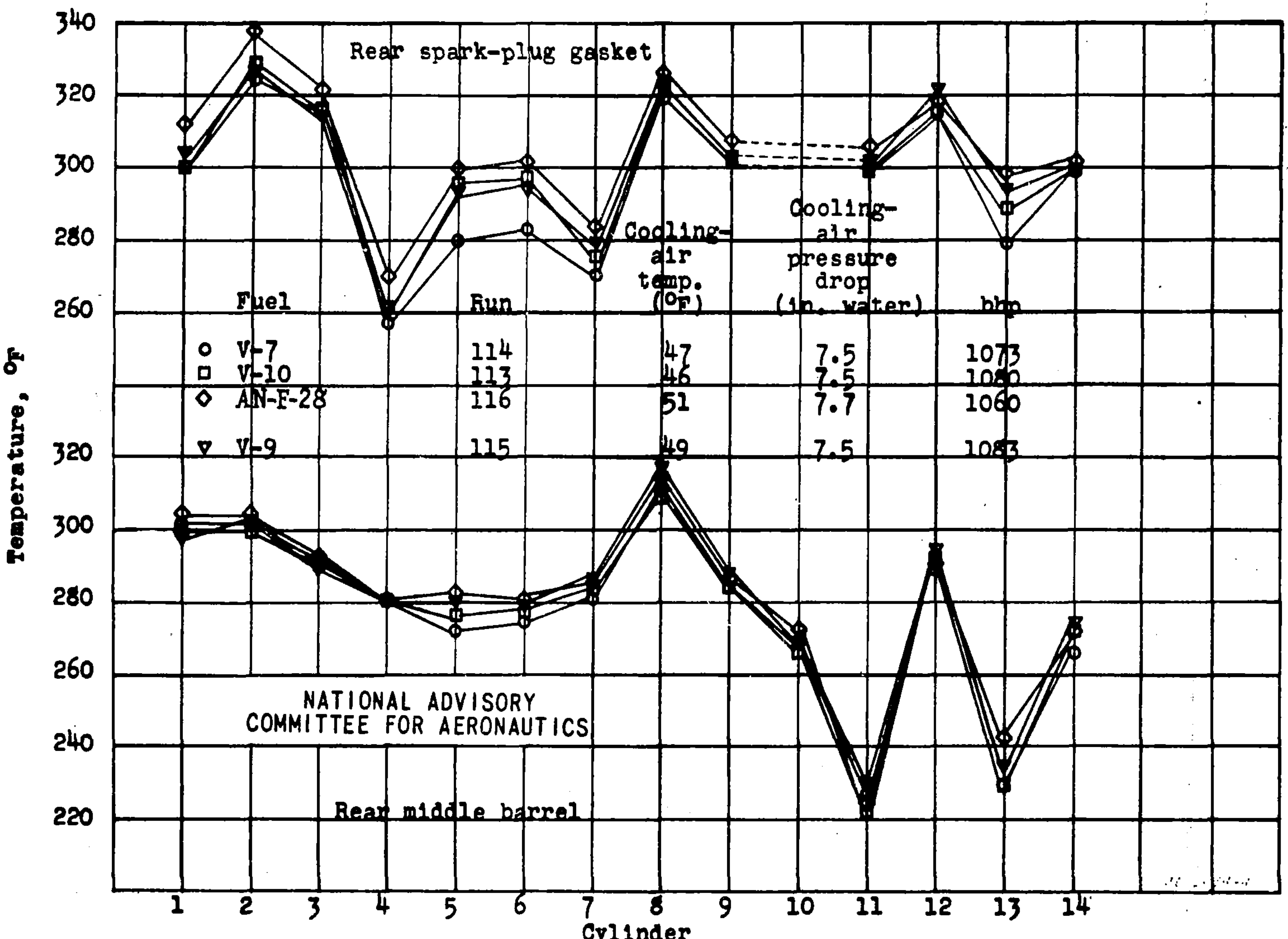
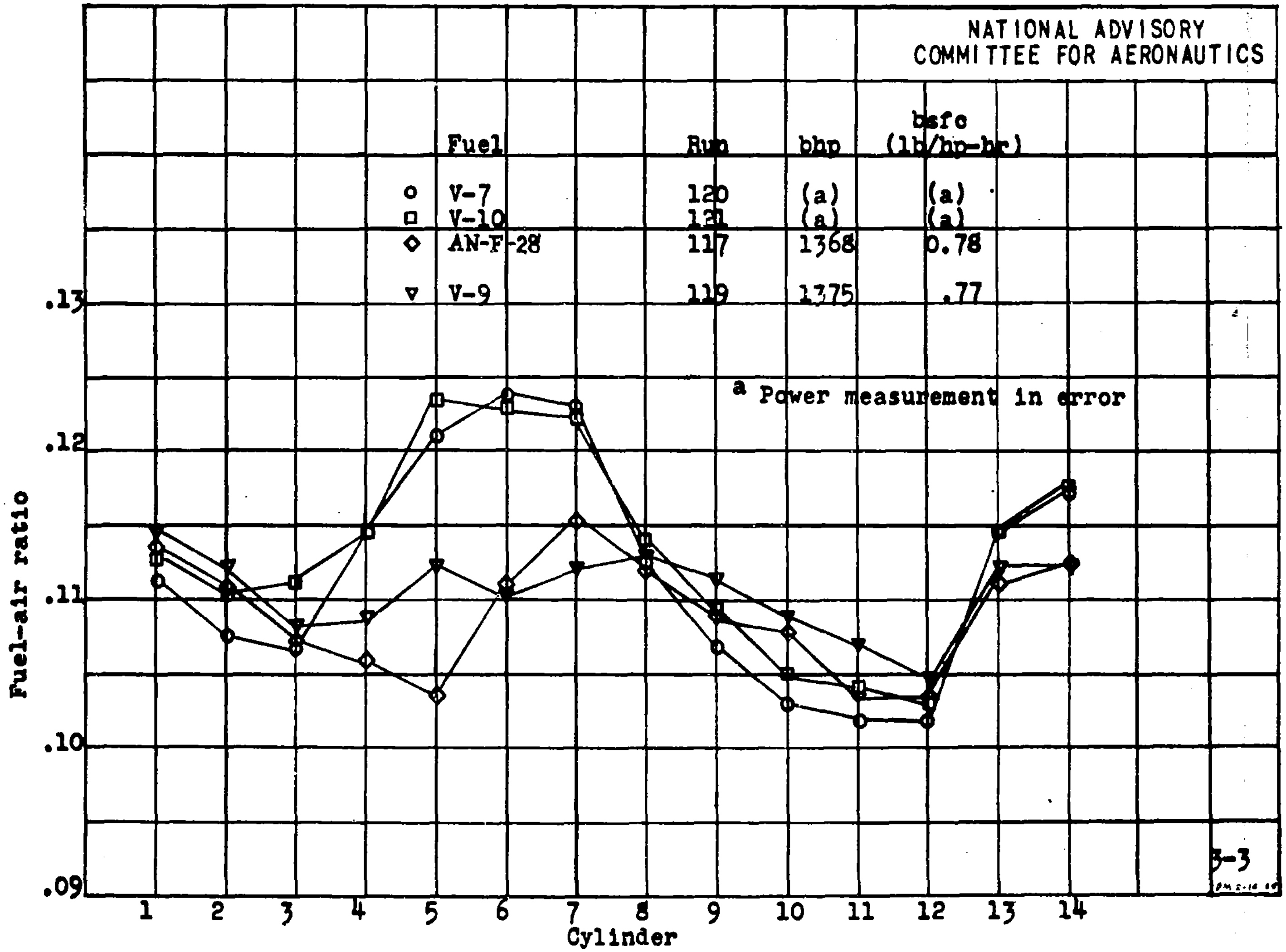
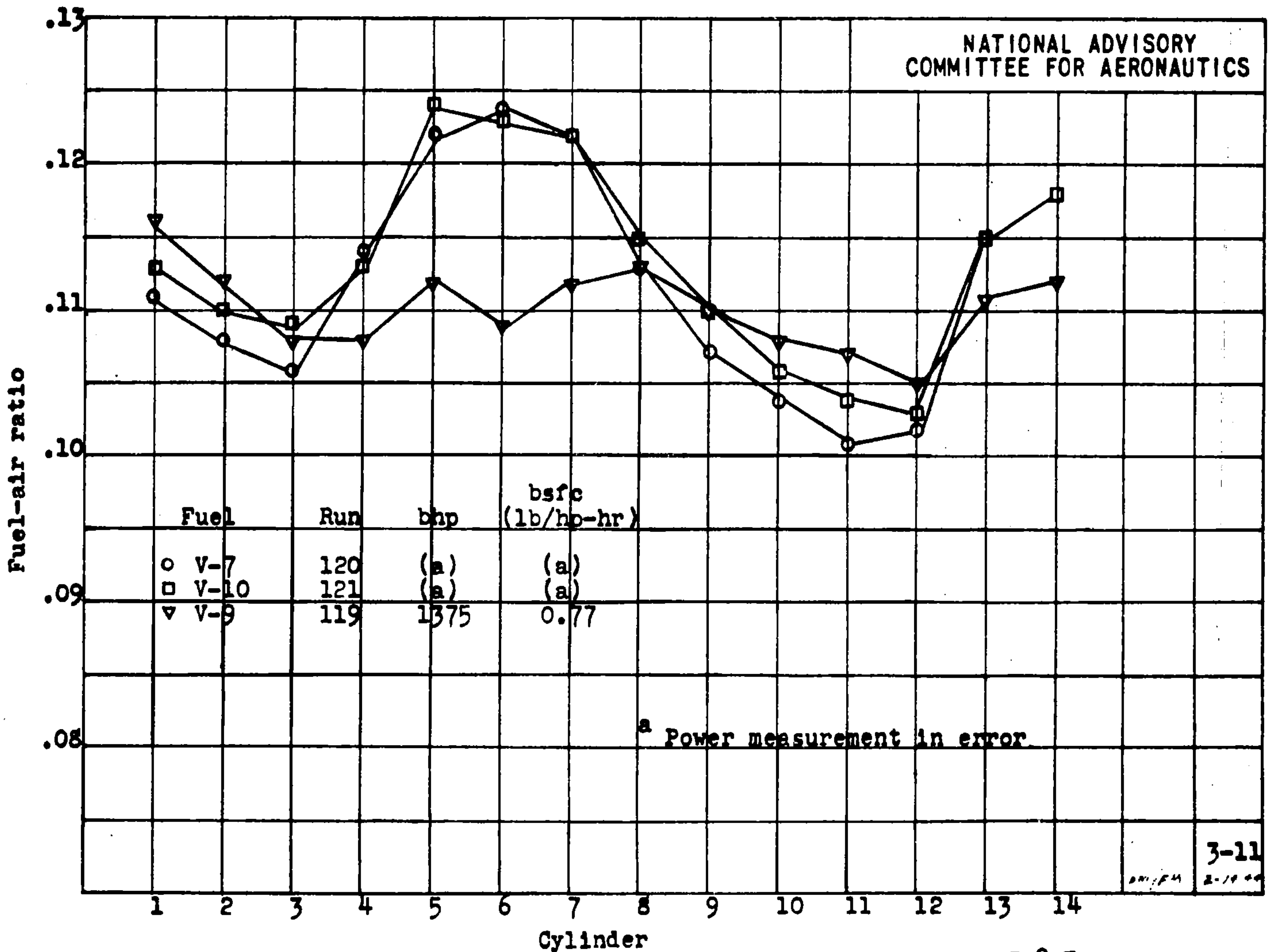


Figure 5. - Temperature distribution of a Wright R-2600-8 engine at 75 percent of normal rated power. Engine speed, 2100 rpm; manifold pressure, 31.0 inches of mercury absolute; carburetor setting, cruising lean; approximate carburetor fuel-air ratio, 0.08.



(a) Orsat (oxidized exhaust) analysis; combustion-air temperature, 68±4° F.

Figure 6. - Mixture distribution of a Wright R-2600-8 engine at normal rated power. Engine speed, 2400 rpm; manifold pressure, 37.5 inches of mercury absolute; carburetor setting, full rich; approximate carburetor fuel-air ratio, 0.12.



(b) Burrell (oxidized exhaust) analysis; combustion-air temperature, 72° F.
Figure 6. - Concluded.

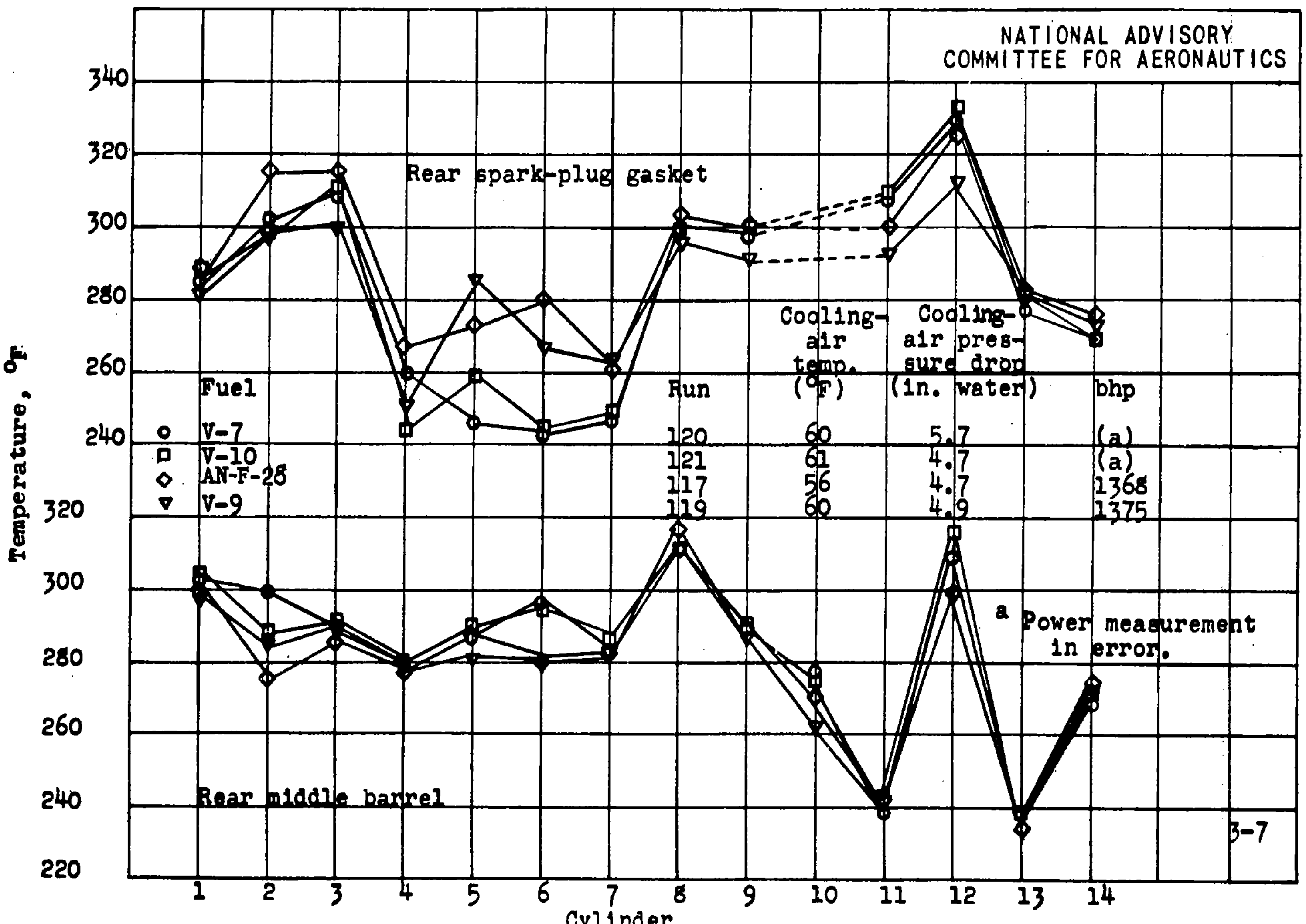


Figure 7. - Temperature distribution of a Wright R-2600-8 engine at normal rated power. Engine speed, 2400 rpm; manifold pressure, 37.5 inches of mercury absolute; carburetor setting, full rich; approximate carburetor fuel-air ratio, 0.12.

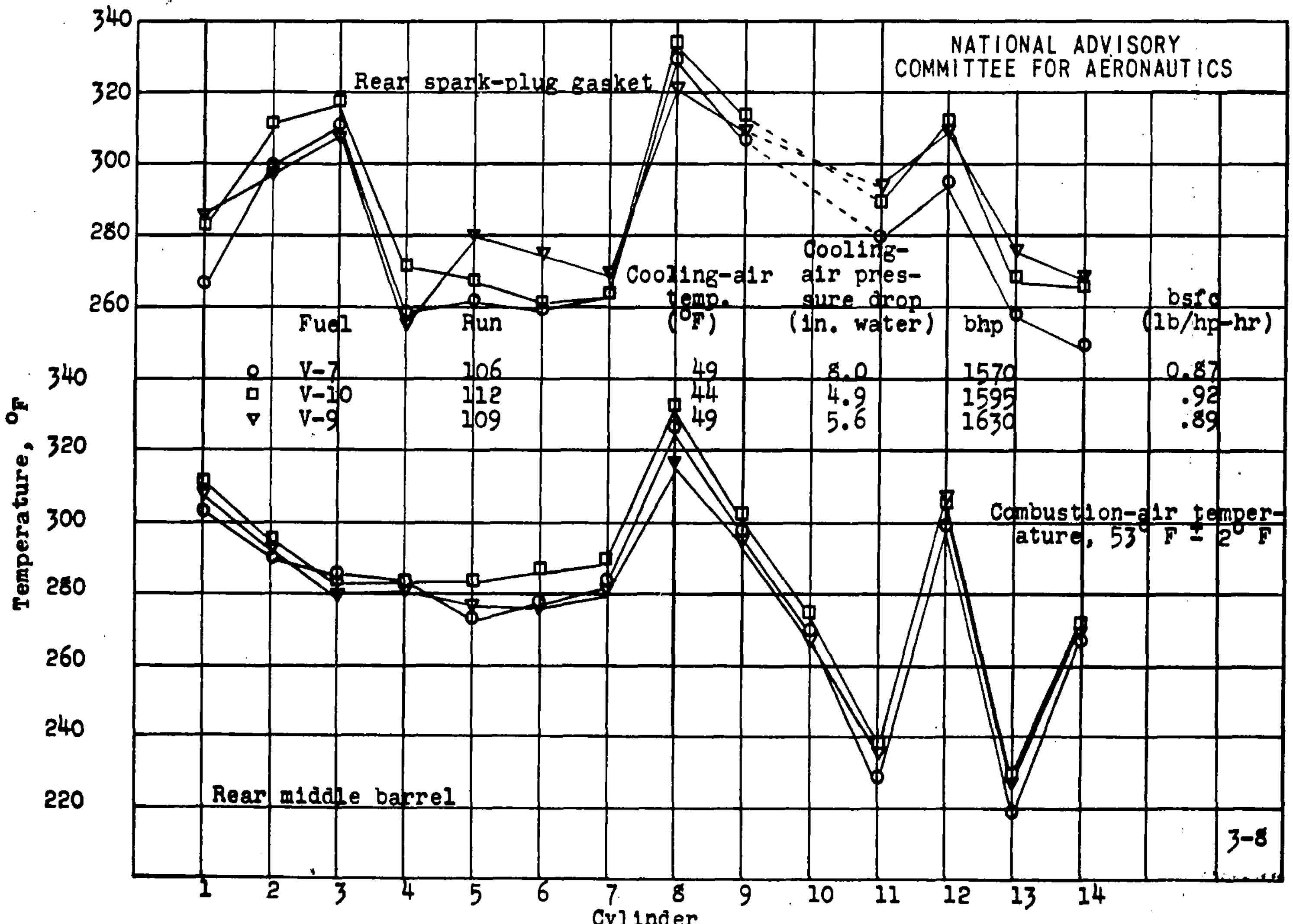
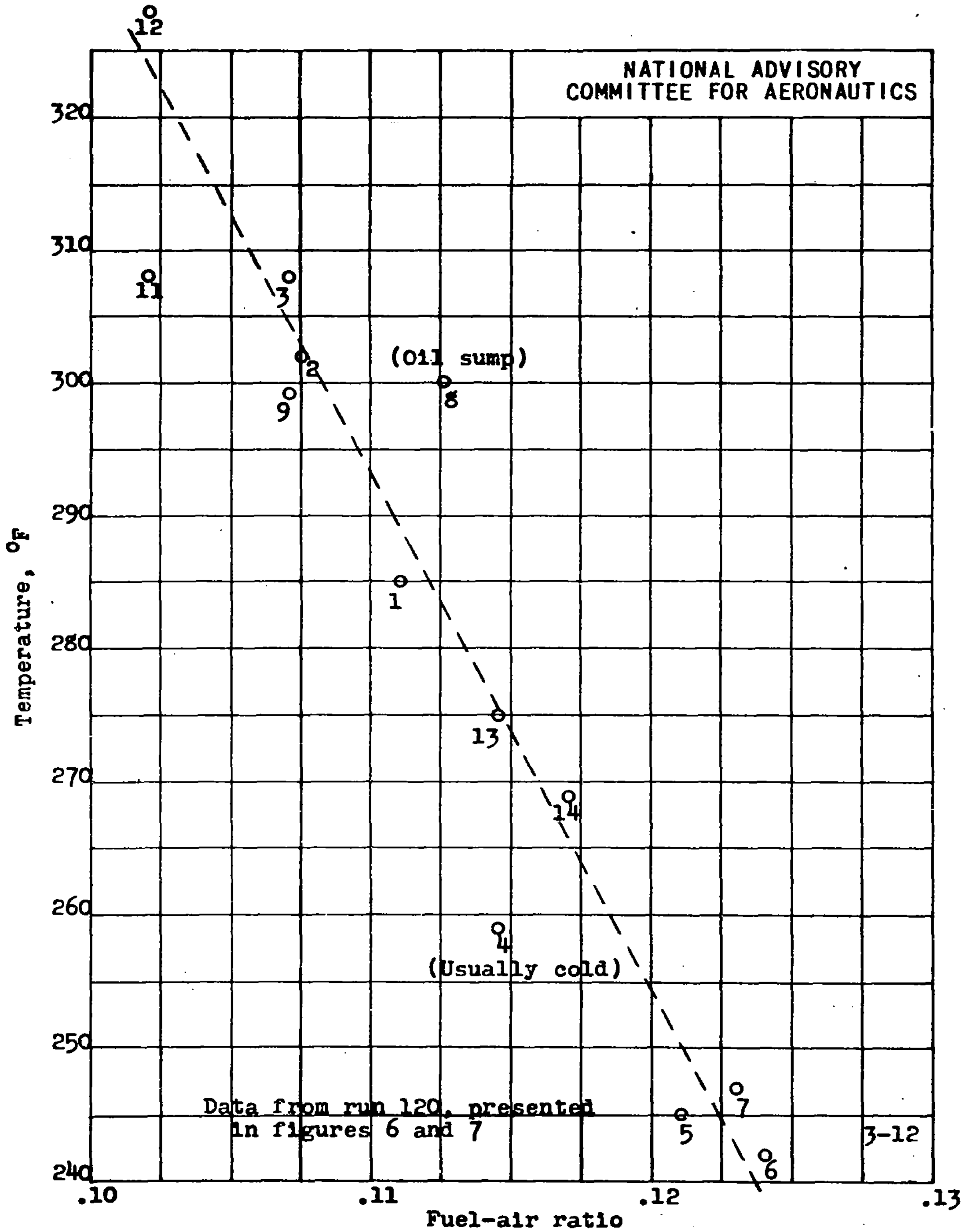
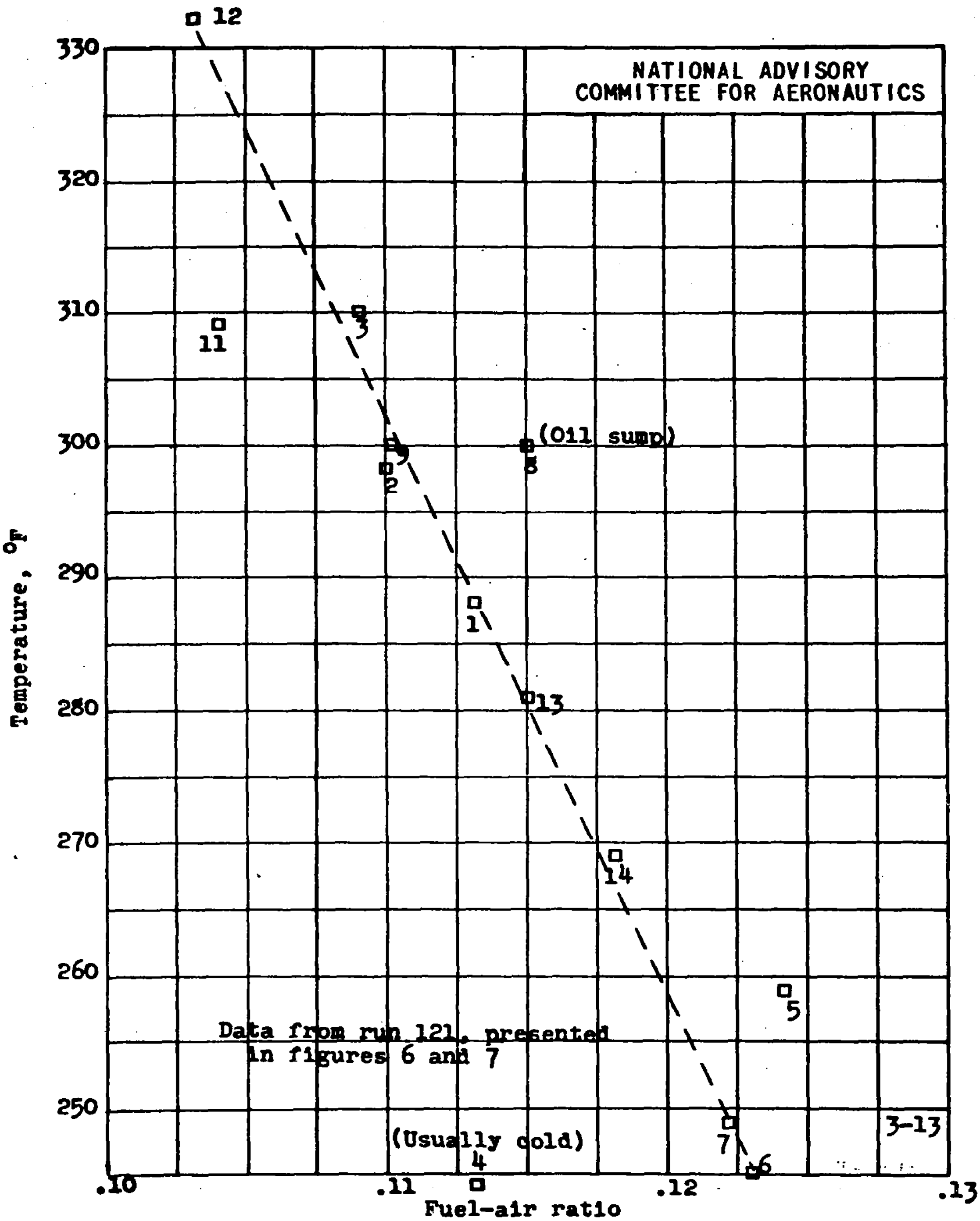


Figure 8. - Temperature distribution of a Wright R-2600-8 engine at take-off power. Engine speed, 2600 rpm; manifold pressure, 43 inches of mercury absolute; carburetor setting, full rich; approximate carburetor fuel-air ratio, 0.13.

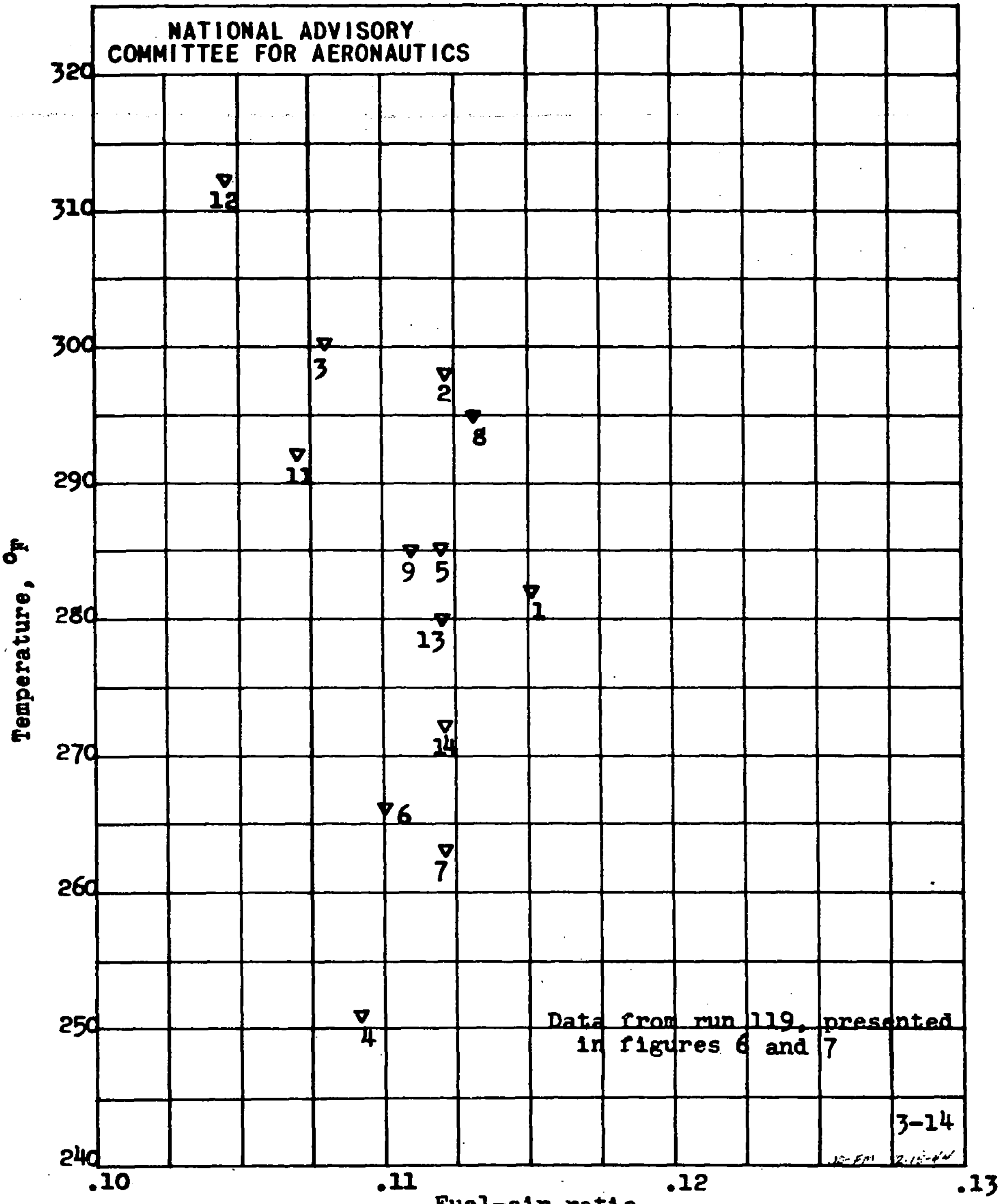


(a) Fuel, V-7; run 120; cooling-air pressure drop, 5.7 inches of water.

Figure 9. - Plot of rear spark-plug-gasket temperature against cylinder mixture strength on a Wright R-2600-8 engine at normal rated power. Engine speed, 2400 rpm; manifold pressure, 37.5 inches of mercury absolute; carburetor setting, full rich; observed fuel-air ratio, 0.12.



(b) Fuel, V-10, run 121; cooling-air pressure drop, 4.7 inches of water.
Figure 9. - Continued.



(c) Fuel, V-9, run 119; cooling-air pressure drop, 4.9 inches of water.

Figure 9. - Concluded.

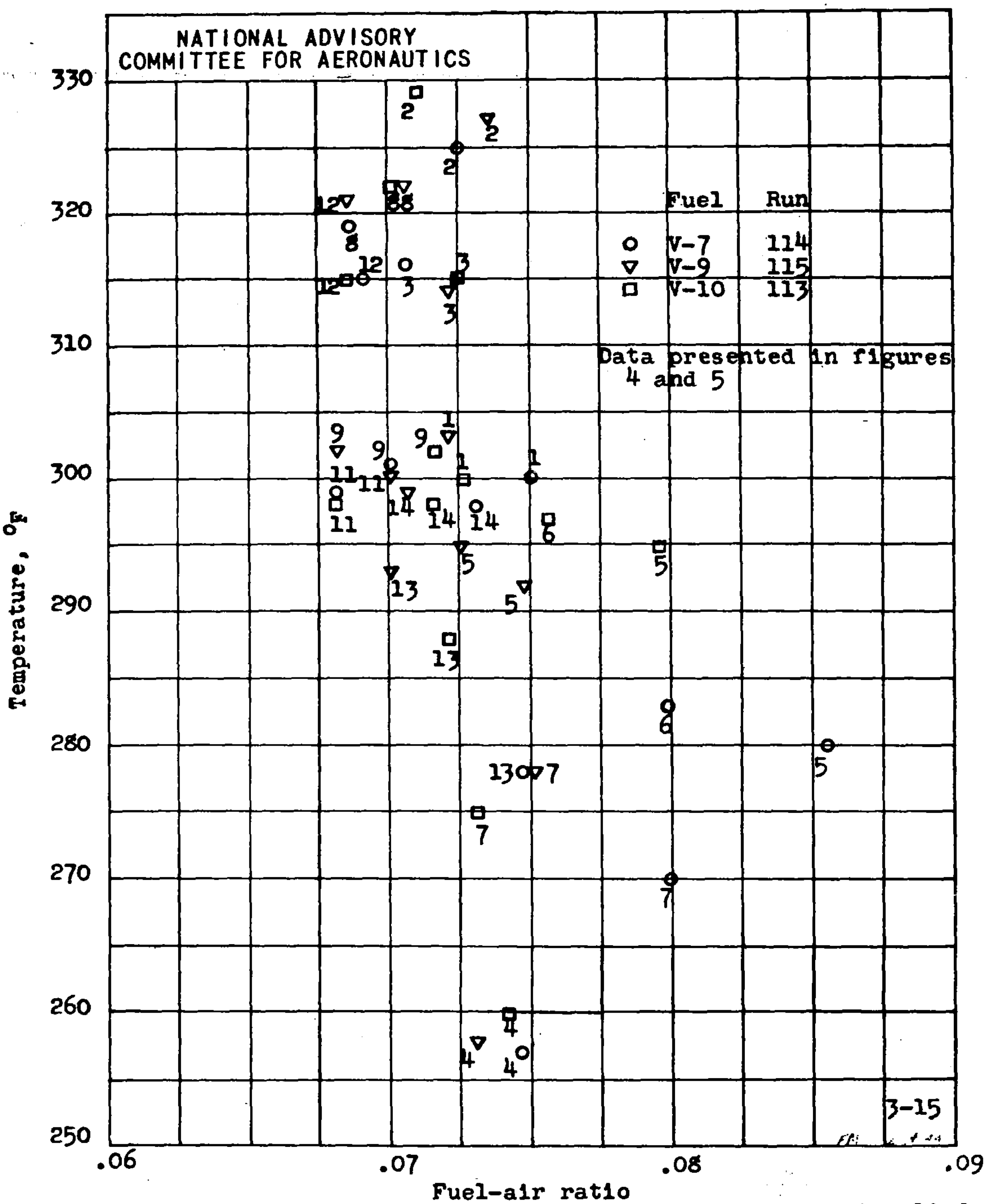


Figure 10. - Plot of rear spark-plug-gasket temperature against cylinder mixture strength on a Wright R-2600-8 engine at 75 percent of normal rated power. Engine speed, 2100 rpm; manifold pressure, 31.0 inches of mercury absolute; carburetor setting, full rich; observed fuel-air ratio, 0.08; cooling-air pressure drop, 7.5 inches of water.

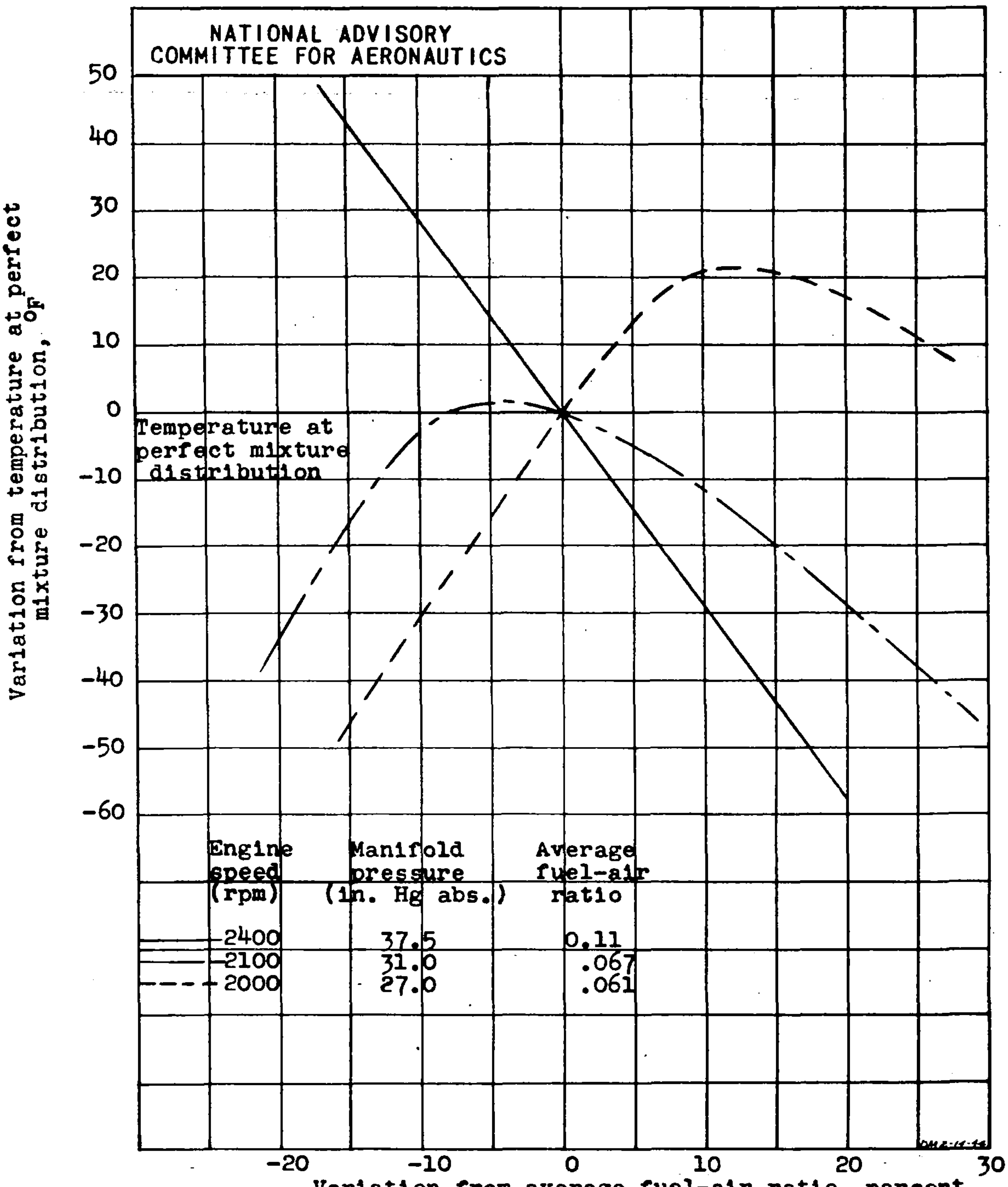


Figure 11. - Variation of rear spark-plug-gasket temperature from temperature at perfect mixture distribution when individual fuel-air ratio varies.